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ABSTRACT

The relationship of Piagetian cognitive modes and integrated science process skills is explored in this study. Specifically, this investigation focused on identifying the hierarchical relationship among Piagetian cognitive modes and integrated science process skills for different Piagetian cognitive reasoning levels and to determine if positive vertical transfers could be validated. Study findings are discussed in relation to: (1) previous studies on hierarchical relationships; (2) the concrete and transitional hierarchies which were identified through a probabilistic latent structure method; (3) explanations for the inability to validate the concrete and transitional hierarchies by the vertical transfer method; and (4) the existence of a developmental hierarchy as opposed to a causal hierarchy. Results of the investigation indicated that a hierarchical link is evident between the Piagetian cognitive modes and integrated science process skills. It is recommended that science curriculum developers and instructional designers incorporate more curriculum activities that reflect both sets of skills and the relationships of the skills. Also included are a listing of 34 references and a compilation of 16 tables and 21 figures. (ML)

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VALIDATION OF HIERARCHICAL RELATIONSHIPS AMONG PIAGETIAN COGNITIVE MODES AND INTEGRATED SCIENCE PROCESS SKILLS FOR DIFFERENT COGNITIVE REASONING LEVELS

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VALIDATION OF HIERARCHICAL RELATIONSHIPS AMONG PIAGETIAN COGNITIVE MODES AND INTEGRATED SCIENCE PROCESS SKILLS FOR DIFFERENT COGNITIVE REASONING LEVELS

INTRODUCTION

Background

As early as the mid-1800s, Huxley, Hooker, and Henslow (Layton, 1973, p. 172) advocated the teaching of science processes in schools. Since then science process skills have become major emphases of curricula developed in the last two decades. Many educators consider the development of science process skills in students to be a major objective of education (e.g., Gagne, 1965; Herron, 1970; Neie, 1972; Okey, 1972). Gagne (1965) contended that science process skills represent common elements in the scientific endeavor as well as carrying the promise of broad transferability across many subject areas. Okey (1972) stated that a major goal of education should be "to teach students how to acquire and process information" (p. 57). He favored process skills that go beyond the acquisition of facts because such skills approximate how students will use or operate on knowledge, in and out of school situations. Padilla (1980) gave the following reasons for the importance of science process skills activities: (1) the skills are generalizable, (2) the skills activities accurately reflect the nature of science, and (3) the skills activities involve the development of formal operation abilities.

Intellectual development of students is another area that has attracted the interest and attention of science educators. A number of science educators have, in one way or another,

indicated its prominence. The stimulation of students' formal reasoning or thinking ability represents a really worthwhile aim of science education, Cohen (1980) noted. Lawson, Karplus and Adi (1978) considered formal operational schemata to be important to student understanding of science content and the process of scientific investigation. Preece (1978) suggested that it is important to match the science taught to the students' level of cognitive development. Similarly, Lawson (1978) noted an increase in awareness of a need to adapt curricula to the developmental levels of learners. Allen (1978) advised science educators to become aware of the cognitive limitations of students. Others like Almy, Chitten and Miller (1966) and Mathews, Phillips and Good (1971) warned that having children engage in activities beyond their cognitive abilities is not only of little value, but such a mismatch of cognitive talents and tasks demands may even by detrimental.

Rationale and Purpose of Study

The importance of the integrated nature of science process skills and intellectual development cannot be denied. Due to the similarities between them, it has been suspected that the Piagetian cognitive modes and integrated science process skills are related in some way.

Attempts to relate the two constructs in the past have been correlational in nature (e.g., Tobin & Capie, 1982; Padilla, Okey and Dillashaw, 1981; Roadrangka, Yeany & Padilla, 1983). The specific nature of the relationship has not been

extensively studied. However, in a paper by Yeany, Yap and Padilla (1984), a hierarchical linkage among the Piagetian cognitive modes and integrated science process skills together with the methodology was proposed.

The methodology used by Yeany, Yap and Padilla (1984) was psychometric in nature. While it may be satisfying to determine hierarchies using psychometric methodologies, it should be more helpful and useful to science educators to determine whether the attainment of subordinate skills can help facilitate attainment of superordinate skills based on previous psychometrically determined 'best' hierarchy. A number of researchers (e.g. White & Gagne, 1974; Carroll, 1973; Griffiths, 1979, 1982; Bergan, 1980; Griffiths, Kass & Cornish,1983) lend support to this procedure of vertical transfer validation. Additionally, students in different Piagetian cognitive reasoning levels operate differently in their thinking, it appears reasonable to hypothesize that the hierarchical linkage at each level may be different.

Thus, this study was designed to identify the hierarchical relationship among Piagetian cognitive modes and integrated science process skills for different Piagetian cognitive reasoning levels and to determine whether positive vertical transfers are validated. Specifically, answers to the following questions were initially sought:

(1) What are the possible hierarchical relationships among Piagetian cognitive modes and integrated science process skills for the concrete, transitional and formal reasoning levels?

(2) Using an alternative analysis procedure, are the possible hierarchical relationships hypothesized for the reasoning levels in question (1) confirmed?

(3) If more than one hierarchical relationship for each reasoning level is confirmed from question (2), which is the best-fit hierarchical relationship for each of the reasoning levels?

(4) Based on the best-fit hierarchical relationship for each of the reasoning levels, are positive vertical transfers observed ?

The above questions indicate the original intention and interest of the study. However, from an initial analysis of the data collected, a hierarchy for the group of students at the formal stage of intellectual development could not be identified. In order for a hierarchical relationship to exist, the data need to fit a pattern of variation. Thus, one reason why it was not possible to obtain a hierarchical relationship is probably because most of the students in the formal group passed most of the Piagetian cognitive modes and integrated science process skills exercises. Therefore, there was inadequate variance in these data to identify a hierarchical pattern. Another reason could be because the measures used were not sensitive enough.

PROCEDURES

The following steps describe how the research was carried out (see Figure 1).

< Insert Figure 1 about here >

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1. Group Assessment of Logical Thinking (GALT) developed by Roadrangka, Yeany, and Padilla (1983) was administered to the experimental sample to enable each student to be categorized into one of the three Piagetian cognitive levels and to provide empirical data on the students' performance on six Piagetian cognitive skills.
2. The Test of Integrated Process Skills (TIPS II) developed by Burns, Wise, and Okey (1983) was administered to provide data on student performance on five integrated science process skills.
3. Based on the procedure described by Roadrangka, Yeany and Padilla (1983), students were categorized into one of the three Piagetian cognitive reasoning levels.
4. For each Piagetian cognitive reasoning level, the ordering theoretic procedure (through a computer program by Lele & Bart, 1971) was employed to obtain possible hierarchical relationships.
5. For each Piagetian cognitive reasoning level and based on the possible hierarchical relationships identified through the ordering theoretic procedure (Bart & Airasian, 1974), Dayton and Macready's probabilistic latent structure method (Dayton & Macready, 1976) was used to identify the best-fit hierarchy for the set of skills.

6. Where more than one subhierarchy was validated for the same set of data, Dayton and Macready's method was used to determine the subhierarchy that yielded the best fit.
7. Having identified the best-fit hierarchy for each Piagetian cognitive reasoning level, sets of subordinate and related superordinate skills were tested for validation by the vertical transfer method.
8. First students who had failed in a set of the subordinate and related superordinate skills were identified.
9. Review lessons and instruction on the relevant subordinate skills were provided for the students identified in step 8.
10. Having completed the review lessons and instruction, the students were then tested on the set of subordinate and related superordinate skills using the same items in GALT and TIPS II.
11. The new data were analyzed for vertical transfer from the subordinate skills to the superordinate skills.
12. Steps 8 to 11 were repeated for each set of the subordinate and related superordinate skills identified in step 7.

Seven hundred and forty one middle and high school science students in grades 7 to 12 participated in this study. Intact

classes were used for the first stage when the GALT and TIPS II were first administered. Of the 741 students, 113 were categorized at the formal level of cognitive reasoning, 162 at the transitional level and 466 at the concrete level.

The review lessons and instruction were characterized by the following: (1) Analogous tasks to those posed in GALT and TIPS II were presented, (2) One set of the actual materials for each of the subordinate tasks was demonstrated to the class, (3) Pupils were required to engage in some activities related to the task on a prepared worksheet, (4) For each task, all possible incorrect answers were discussed and shown why they are incorrect, (5) The correct answers were discussed and shown why they are correct, (6) Very specific instructions and guidelines were given to both the teachers and students in all the materials handed out.

ANALYSIS OF DATA

To answer Research Question 1, the data from students' performance on GALT and TIPS II were analyzed with the help of the computer program by Lele and Bart (1971). To determine the acceptance or rejection of prerequisite relations, tolerance levels can be set at 5%, 10% and 20%. (For skill 1 to be a prerequisite of skill 2, there should be no examinees who pass skill 2 and yet fail skill 1. A tolerance level of 20% means that for a sample size of 100, skill 1 may be considered to be a prerequisite of skill 2 if not more than 20 examinees pass skill 2 while failing skill 1).

In order to answer Research Question 2, each of the hierarchical relationships identified under Question 1 was used as the basis for a systematic 'search' for a best-fit hierarchy. The analysis was done using subsets of 4 or 5 skills. To evaluate the validity of a subhierarchy, estimates of the following are considered: α ('guessing parameter'), β ('forgetting' parameter), and the 'p' value. For 'reasonable' values of α and β, a subhierarchy was considered 'valid' if the 'p' value is greater than Ø.Ø5. The statistic for evaluating the goodness-of-fit test is the maximum likelihood ratio (L), which is a chi-squared statistic with the degrees of freedom, $df=2^q-k-2$ (where q=number of skills and k=number of defining patterns).

In order to answer Research Question 3, the validated hierarchical relationships were compared. To test whether two subhierarchies for the same subset of skills fit the data equally well, the difference between the two maximum likelihood ratios, (L2 - L1), is computed; and, for the difference in degrees of freedom (df2 - df1), the corresponding 'p' value obtained. If the 'p' value was less than Ø.Ø5, then one of the subhierarchies probably fit the data better. This test together with the estimates for α, β, and 'p' value was used to suggest the best-fit hierarchy for the data.

The general null form of the hypothesis for the Research Question 4 is: The proportion of students who pass the subordinate skill and also pass the superordinate skill is equal to or less than the proportion of students who fail the subordinate skill and pass the superordinate skill. For large

enough sample size (greater than 30) and nonzero categories, Pearson's chi squared statistic was employed while for small sample size, Fisher's exact test was used.

RESULTS OF THE STUDY

The total test reliabilities in this study for GALT and TIPS II as measured by Cronbach's alpha were 0.80 and 0.84 respectively. The performance of the concrete students on GALT and TIPS II measures are shown in Tables 1 and 2. Tables 3 and 4 show the performance of the transitional students based on the raw score and criterion-scored data respectively. For the concrete reasoning level, Table 5 shows the frequency of success on each of the GALT and TIPS II measures. Based on this frequency, the order of 'easiness' of the 11 skills are indicated. Combinatorial reasoning and conservation reasoning appear to be the easiest skills to acquire while probability reasoning and identifying variables appear to be the most difficult. Similarly, for the transitional reasoning level, Table 6 shows the frequency of success for the GALT and TIPS II measures. While conservation reasoning and combinatorial reasoning appear the 'easiest' skills for students at this intellectual level, identifying variables and correlational reasoning appear most difficult.

(Insert Tables 1 thru 6 about here)

Results - Using the Ordering Theoretic Procedure

Table 7 presents the hierarchical relationships of the Piagetian cognitive modes and the integrated science process skills for the concrete reasoning level using tolerance levels of 20%, 10% and 5%. At the 5% tolerance level, there are no hierarchical relationships hypothesized. At the 10% tolerance level there are hierarchical relationships hypothesized, but they are not as complex as those hypothesized at the 20% tolerance level. Based on Table 7, diagrammatic representations of the hierarchical relationships at the 10% and 20% tolerance levels are given in Figure 2.

(Insert Figure 2 about here)

Table 8 presents the hierarchical relationships for this intellectual level at the 20%, 10% and 5% tolerance levels. Diagrammatic representations of the hierarchical relationships hypothesized are given in Figure 3.

(Insert Table 8 & Figure 3 about here)

Results - Using Dayton and Macready's Probabilistic Method

Concrete Hierarchy

Although more subsets of skills were actually assessed, Figures 4 to 10 present the various subsets of skills at the concrete reasoning level for which at least one possible subhierarchy was found to suggest a suitable fit using Dayton and Macready's method.

(Insert Figures 4 thru 10 about here)

The results of testing the hypothesized subhierarchies are shown in Table 9. As long as the values of α and β are 'reasonable' and the 'p' values greater than Ø.Ø5 then the data suggest that the subhierarchies are 'valid'. Table 1Ø shows the results of comparing two subhierarchies for the same subset of skills. The statistical test carried out can suggest whether both subhierarchies are an equally good fit. The results of this test together with the α , β and 'p' values can help to decide on the 'best' fit.

(Insert Tables 9 & 1Ø about here)

Combining all the 'best-fit' subhierarchies of Figures 4(a), 5(a), 6(a), 7(a), 8(a) or 8(b), 9(b) and 1Ø(b), a model of the 'best' hierarchy for the concrete reasoning level is shown in Figure 11. The 'best' hierarchy indicates that conservation reasoning, combinatorial reasoning and designing experiments are fundamental skills. Conservation reasoning and combinatorial reasoning are prerequisite skills to proportional reasoning, operationally defining, and graphing and interpreting data. Also, together with designing experiments they are prerequisites to identifying hypotheses. Operationally defining and designing experiments are in turn prerequisites to identifying variables. Together with proportional reasoning, controlling variables and perhaps graphing and interpreting data, identifying variables appears to be prerequisites to probability reasoning. The only skill that did not appear to be involved in any of the hierarchical

relationships at the concrete reasoning level is correlational reasoning.

(Insert Figure 11 about here)

Transitional Hierarchy

Figures 12 to 20 present the various subsets of skills for which at least one possible subhierarchy was tested using Dayton and Macready's Probabilistic method and found to present confirming results of hierarchical relationships. The results of testing the hypothesized subhierarchies in Figures 12 to 20 are presented in Table 11. Table 12 shows the results of comparing two subhierarchies for the same subset of skills.

(Insert Figures 12 & 20 & Table 11 & 12 about here)

Combining all the 'best' subhierarchies of Figures 12, 13, 14, 15, 16(a), 17, 18, 19(b) and 20, the 'best' hierarchy for the transitional reasoning level is described by Figure 21. Combinatorial reasoning and perhaps conservation reasoning are prerequisites to proportional reasoning, probability reasoning and designing experiments. Designing experiments, in turn, is a prerequisite to correlational reasoning, identifying variables, identifying hypotheses, operationally defining and graphing and interpreting data. The results suggest that it is equally possible that operationally defining may be a prerequisite to identifying hypotheses. As such a dashed line is drawn to indicate the alternative.

(Insert Figure 21 about here)

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Results - Vertical Transfer Validation

Vertical Transfer Validation of the Concrete Hierarchy

Table 13 presents the results of testing the vertical transfer of these sets of subordinate-superordinate skills in the hierarchy. Thus, the data suggest that: (1) review on designing experiments, given that the students have previously acquired conservation reasoning and combinatorial reasoning, can facilitate the achievement of identifying hypotheses; (2) review on operationally defining, given that the students have previously acquired designing experiments, conservation reasoning and combinatorial reasoning, can then facilitate the attainment of identifying hypotheses; (3) review on both operationally defining and designing experiments, given that the students have previously acquired conservation reasoning and combinatorial reasoning, can facilitate the attainment of identifying hypotheses; and, (4) given the skills of conservation reasoning and combinatorial reasoning, review on proportional reasoning can facilitate the attainment of probability reasoning. However, there is no evidence to suggest that the other superordinate skills (Table 13) are facilitated by the review of their related subordinate skills.

(Insert Table 13 about here)

Transfer Validation of the Transitional Hierarchy

Table 14 presents the results of testing for vertical transfer of these sets of subordinate and superordinate skills in the transitional hierarchy. Fisher's exact test was used

because of the small sample size. It is observed that the 'p' values were all greater than Ø.1Ø. Thus, there is no evidence to suggest vertical transfer of skills for the transitional reasoning level.

(Insert Table 14 about here)

DISCUSSIONS

Are the hierarchical relationships obtained consistent with those obtained from other studies?

There was some work done on the hierarchical relationships among the basic process skills by AAAS under the direction of Walbesser (AAAS, 1965; Walbesser, H. H., 1968). However, there is no evidence in the literature that any hierarchical relationships were established for the integrated science process skills. While there is no direct effort to establish hierarchical relationships among the Piagetian cognitive modes, implications of hierarchical relationships appear in the writings of Piaget and a few Piagetian researchers. In their book, The Growth of Logical Thinking - from Childhood to Adolescence (1958), Inhelder and Piaget suggested that combinatorial reasoning is a prerequisite to controlling variables (p. 55), and controlling variables, in turn, is a prerequisite to formulation of hypotheses (p. 58). Further on in their book (p. 233-234), they also suggested that combinatorial reasoning and proportional reasoning are necessary for correlational reasoning. Lawson (1983) had also predicted that probability reasoning and proportional reasoning are prerequisites to correlational reasoning. Thus for the

Piagetian cognitive modes, an integration of the above implications seem to suggest a subhierarchy of the following:

formulation of hypotheses

controlling variables correlational reasoning

combinatorial reasoning proportional reasoning probability reasoning

At the concrete reasoning level, the hierarchy obtained using Dayton and Macready's probabilistic method has been presented in Figure 11. Looking at just the Piagetian cognitive modes, combinatorial reasoning, conservation reasoning, proportional reasoning and controlling variables are all prerequisites to probability reasoning. Combinatorial reasoning together with conservation reasoning appeared to be prerequisites to proportional reasoning but not controlling variables. At the transitional reasoning level, the hierarchy obtained using Dayton and Macready's probabilistic method has been shown in Figure 21. At this level, combinatorial reasoning together with conservation reasoning appeared to be prerequisites to proportional reasoning, probability reasoning and correlational reasoning. However, proportional reasoning and probability reasoning did not seemed to be prerequisites to correlational reasoning. Thus the results from this study appear to support in some respects the 'intuition' and implications of a number of researchers. At the same time, the study has presented results that appeared to contradict the implications in the

literature mentioned above. As more research efforts are put into this direction, there will be more refinements to the hierarchies presented in this study.

Is there any logical explanation for the concrete and transitional hierarchies obtained by Dayton and Macready's probabilistic method?

Conservation reasoning and combinatorial reasoning as fundamental skills are consistent with Piaget's theory. Thus, the hierarchies of the Piagetian cognitive modes presented in Figure 11 and Figure 21 are generally consistent in terms of the levels of hierarchy but perhaps not in terms of the fine structure. It appears logical that proportional reasoning should be a prerequisite of probability reasoning if the items in GALT were evaluated objectively. In order to answer the probability items the students were required to use proportions. Although for the concrete reasoning level, this hierarchical relationship appears to be supported (Figure 11), it is not for the transitional reasoning level (Figure 21). At this present stage, the explanations may still be lacking for some of the hierarchical relationships. For example, why is graphing & interpreting data a prerequisite for probability reasoning at the concrete reasoning level? Perhaps the explanation is related to the need to use proportional scales in graphing and interpreting data. Why is this not true at the transitional reasoning level? Why is identifying variables a prerequisite of probability reasoning? Why is designing experiments a prerequisite to both identifying variables and identifying hypotheses? Logically one would expect that the

ability to design experiments is dependent on the ability to identifying variables and identifying hypotheses among perhaps other skills. These are some of a number of questions that require some logical explanations. While science educators lament the fact that Piaget's theory does not really help in curriculum development, the results of this study have presented reasonable hierarchical relationships for different cognitive levels that must now satisfy some logical explanations so that they be implemented more confidently in curriculum development and instructional design.

What are possible explanations for the inability to validate the concrete and transitional hierarchies by the Vertical Transfer method?

One explanation for the inability to validate the concrete and transitional hierarchies obtained by Dayton and Macready's method is that these hierarchies are, in the first place, incorrect. As such, review of the subordinate skills based on these hierarchies will not facilitate the attainment of related superordinate skills. This explanation probably does not hold well. The model proposed by Dayton and Macready is based on very sound reasonings and well supported by mathematical formulations. It takes into consideration various objections and weaknesses of previous methodologies. Furthermore, the data in this study appear to fit reasonably well the hierarchies presented.

Another possibly more reasonable explanation is that a large portion of the hierarchies are correct but incomplete. In other words, there are other closely related skills that

were omitted or that the existing skills need to be more specifically defined. For example, instead of just being able to identify hypotheses, the ability to formulate hypotheses and to suggest alternative hypotheses may need to be included. Also, it may be necessary to redefine proportional reasoning such that the ability in direct proportionality and the ability in inverse proportionality are distinguished. Similarly, for the other skills, there may be a necessity for more refined definitions. If these skills were included, perhaps we would obtain a more refined hierarchy. A more complete review would then help to facilitate the attainment of related superordinate skills.

However, assuming that these hierarchies are correct, it is possible that the instruction needs to be improved so as to be more effective. Tables 15 and 16 indicate that the percentage of passes compared to that of failures are in many cases higher. This, in part, indicates that instruction has

(Insert Tables 15 & 16 about here)

been helpful to facilitate the learning of subordinate skills. Nevertheless, one is not sure whether it is just superficial learning that enable them to answer the test items correctly since they are so similar to the review items. Although this superficial learning enables some students to pass the subordinate skills, it is not sufficient to enable passing the superordinate skills. Particularly, for these superficial learners, it may be that more review lessons, more variety of examples and practice, and more interactions with both peers and teachers are required.

Yet another explanation could be provided by the answer to the next question.

Are there two types of hierarchies?

Attempts to validate hierarchies obtained by Dayton and Macready's method using the vertical transfer method have not been too successful as indicated in this study and that of others (Griffiths, Kass, & Cornish, 1983). This has raised a suggestion to the possibility of the existence of two types of hierarchies - a developmental or static hierarchy as opposed to a causal or dynamic hierarchy. A developmental or static hierarchy refers to one which is dependent on the intellectual development of the individual as in concrete and transitional reasoning levels. Dayton and Macready's probabilistic method may determine a developmental hierarchy. A causal or dynamic hierarchy refers to one where the prerequisite skills determine the ability to perform on the related superordinate skills. To further distinguish these types of hierarchies, one could consider crawling and walking. Crawling is a physical ability that is normally exhibited earlier than walking. Among a group of very young children, there are probably more who cannot crawl and cannot walk than there are who cannot crawl but can walk. Yet, it does not mean that the ability to crawl is a prerequisite to walking. Thus, while the vertical transfer method validates a causal or dynamic hierarchy, the hierarchies for concrete reasoning and transitional reasoning obtained using Dayton and Macready's method may be developmental and causal. This may, in part, explain why some of hierarchical relationships were validated by the vertical transfer method while others were not.

IMPLICATIONS OF RESULTS

The implications of the results and discussions above are wide and important. That there is some form of hierarchical link between the Piagetian cognitive modes and integrated science process skills is highly evident. Thus, science curriculum developers, instructional designers, teachers, teacher trainers and researchers need to be aware of the link and interdependence of both sets of skills. Furthermore, they need to be aware of the exact nature of the hierarchy for different cognitive reasoning levels. Science education researchers need to put more efforts into this type of research so that the hierarchies obtained can be further refined to an adequate level. It is also important for science education researchers to distinguish and determine a developmental (or static) and a causal (or dynamic) hierarchy. If there is a difference, it has also slightly different implications. For example, if evidence indicates a developmental hierarchical relationship, then perhaps it means that certain skills can be neglected until a more appropriate time? On the other hand, if it is causal then learning difficulties would result by neglecting the skills. Such difficulties may then result in permanent damage. Science curriculum developers and instructional designers need to incorporate more curriculum activities that reflect not only both sets of skills but also the subordinate and superordinate relationships of the skills. For different skills and different groups of students under different conditions, different instructional designs are required. Science teachers should systematically and

periodically assess and monitor the entry level and progress of their students. By checking on the status of their students, teachers are then better equipped to prescribe appropriate materials and instruction to facilitate the development of their students.

Belanger (1969) suggested that Piaget's levels of intellectual development are extremely broad and lack the prerequisite sequencing necessary for curriculum development. Perhaps the findings of this study can provide some fine structure required to be helpful in curriculum development and instructional design. Instead of focusing on integrated science process skills or intellectual development alone, one can view these two sets of intellectual skills together and attempt to use the findings to formulate instructional and curriculum sequencing decisions. A validated hierarchical relationship will serve as a guide for classroom teachers to emphasize the intellectual skills in the correct sequence for a particular group of students. It may also be useful for classroom teachers to plan and conduct review programs for different groups of students. The findings of such a study may also help teachers to diagnose the underlying reason for the difficulties that their students encounter. For the science education researchers, such a study can definitely open up more in-depth studies that would be of tremendous help to the practitioners. Such a study can also stimulate further interest and pursuit for an underlying construct that integrates the two sets of skills.

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Table 1

Descriptive Statistics on GALT and TIPS II Measures for the Concrete Students Based on Raw Data

Measure	N	Mean Score	Mean Score in %	Standard Deviation	Standard Error of Mean	Minimum Score	Maximum Score	Maximum Possible Score
Conservation Reasoning	465	0.93	47	0.69	0.03	0	2	2
Proportional Reasoning	466	0.13	7	0.36	0.02	0	2	2
Controlling Variables	465	0.24	12	0.47	0.02	0	2	2
Probability Reasoning	466	0.06	3	0.28	0.01	0	2	2
Correlational Reasoning	466	0.10	5	0.30	0.01	0	1	2
Combinatorial Reasoning	466	0.79	40	0.52	0.02	0	2	2
GALT	465	2.25	19	1.16	0.05	0	4	12
Identifying Variables	469	4.85	40	1.85	0.09	0	10	12
Identifying Hypotheses	465	3.35	38	1.77	0.08	0	9	9
Operational Defining	465	2.68	45	1.48	0.07	0	6	6
Designing Experiments	466	1.58	53	0.96	0.04	0	3	3
Graphing and Interpreting Data	466	2.59	43	1.44	0.07	0	6	6
TIPS II	464	15.03	42	5.08	0.24	4	30	36

Table 2

Descriptive Statistics on GALT and TIPS II Measures
for the Concrete Students Based on Criterion-Scored Data

Measure	N	Mean Score	Mean Score in %	Standard Deviation	Standard Error of Mean	Minimum Score	Maximum Score	Maximum Possible Score
Conservation Reasoning	465	0.73	73	0.45	0.02	0	1	1
Proportional Reasoning	465	0.12	12	0.33	0.02	0	1	1
Controlling Variables	465	0.22	22	0.41	0.02	0	1	1
Probability Reasoning	466	0.06	6	0.23	0.01	0	1	1
Correlational Reasoning	465	0.10	10	0.30	0.01	0	1	1
Combinatorial Reasoning	466	0.74	74	0.44	0.02	0	1	1
GALT	465	1.96	33	0.93	0.04	0	4	6
Identifying Variables	464	0.08	8	0.28	0.01	0	1	1
Identifying Hypotheses	466	0.13	13	0.34	0.02	0	1	1
Operational Defining	466	0.28	28	0.45	0.02	0	1	1
Designing Experiments	466	0.51	51	0.50	0.02	0	1	1
Graphing and Interpreting Data	465	0.26	26	0.44	0.02	0	1	1
TIPS II	464	1.27	25	1.24	0.06	0	5	5

Table 3

Descriptive Statistics on GALT and TIPS II Measures for the Transitional Students Based on Raw Score Data

Measure	N	Mean Score	Mean Score in %	Standard Deviation	Standard Error of Mean	Minimum Score	Maximum Score	Maximum Possible Score
Conservation Reasoning	162	1.65	82	0.52	0.04	0	2	2
Proportional Reasoning	162	0.83	41	0.65	0.05	0	2	2
Controlling Variables	162	0.94	47	0.67	0.05	0	2	2
Probability Reasoning	162	0.74	37	0.89	0.07	0	2	2
Correlational Reasoning	162	0.20	10	0.44	0.03	0	2	2
Combinatorial Reasoning	162	1.47	76	0.56	0.04	0	2	2
GALT	162	5.83	49	0.87	0.07	5	7	12
Identifying Variables	162	6.17	50	2.08	0.16	2	12	12
Identifying Hypotheses	162	5.05	56	1.86	0.15	1	9	9
Operational Defining	162	3.91	65	1.34	0.11	1	6	6
Designing Experiments	162	2.35	78	0.80	0.06	0	3	3
Graphing and Interpreting Data	162	3.82	64	1.35	0.11	0	6	6
TIPS II	162	21.30	59	4.95	0.39	5	33	36

Table 4

Descriptive Statistics on GALT and TIPS II Measures
for the Transitional Students Based on Criteria Scored Data

Measure	N	Mean Score	Mean Score in %	Standard Deviation	Standard Error of Mean	Minimum Score	Maximum Score	Maximum Possible Score
Conservation Reasoning	162	0.98	98	0.14	0.01	0	1	1
Proportional Reasoning	162	0.69	69	0.46	0.04	0	1	1
Reasoning Controlling	162	0.75	75	0.44	0.03	0	1	1
Variables Probability	162	.44	44	0.50	0.04	0	1	1
Correlational Reasoning	162	0.19	19	0.40	0.03	0	1	1
Combinatorial Reasoning	162	0.97	97	0.17	0.01	0	1	1
GALT	162	4.03	67	0.70	0.06	3	6	6
Identifying Variables	162	0.23	23	0.42	0.03	0	1	1
Identifying Hypotheses	162	0.43	43	0.50	0.04	0	1	1
Operational Defining	162	0.61	61	0.49	0.04	0	1	1
Designing Experiments	162	0.85	85	0.36	0.03	0	1	1
Graphing and Interpreting Data	162	0.59	59	0.49	0.04	0	1	1
TIPS II	162	2.71	54	1.39	0.11	0	5	5

Table 5

Frequency and Percent of Correct Answers for GALT and TIPS II Measures at the Concrete Reasoning Level (N = 466)

Measures	Frequency	Percent(%)	Rank of 'Easiness'
GALT			
Conservation Reasoning	339	72.90	2
Proportional Reasoning	58	12.47	8
Controlling Variables	101	21.72	6
Probability Reasoning	26	5.59	11
Correlational Reasoning	45	9.68	9
Combinatorial Reasoning	344	73.98	1
TIPS II			
Identifying Variables	39	8.41	10
Identifying Hypotheses	61	13.12	7
Operationally Defining	132	28.39	4
Designing Experiments	239	51.40	3
Graphing and Interpreting Data	123	26.45	5

Table 6

Frequency and Percent of Correct Answers for GALT and TIPS II Measures at the Transitional Reasoning Level (N = 162)

Measures	Frequency	Percent(%)	Rank of 'Easiness'
GALT			
Conservation Reasoning	159	98.15	1
Proportional Reasoning	112	69.14	5
Controlling Variables	121	74.69	4
Probability Reasoning	72	44.44	8
Correlational Reasoning	31	19.14	11
Combinatorial Reasoning	157	96.91	2
TIPS II			
Identifying Variables	37	22.84	10
Identifying Hypotheses	70	43.21	9
Operationally Defining	99	61.11	6
Designing Experiments	137	84.57	3
Graphing and Interpreting Data	96	59.26	7

Table 7

Hierarchical Relationships Using Ordering Theoretic Method for the Concrete Reasoning Level

Tolerance Level (%)	Skill P.....is prerequisite to Skills 1, 2, ...etc	
20%	Combinatorial	Proportional Reasoning, Identifying Variables, Identifying Hypotheses, Operationally Defining, Graphing & Interpreting Data
	Conservation Reasoning	Proportional Reasoning, Identifying Hypotheses, Operationally Defining, Designing Experiments, Graphing & Interpreting Data.
10%	Combinatorial Reasoning	Identifying Hypotheses
	Conservation Reasoning	Proportional Reasoning
5%	-	-

Table 8

Hierarchical Relationships Using Ordering Theoretic Method for the Transitional Reasoning Level

Tolerance Level (%)	Skill P.....is prerequisite to Skills 1, 2, ...etc	
20%	Conservation Reasoning	Combinatorial Reasoning
	Combinatorial Reasoning	Designing Experiments
	Designing Experiments	Conservation Reasoning, Proportional Reasoning, Controlling Variables, Probability Reasoning, Correlational Reasoning, Identifying Variables, Graphing & Interpreting Data.
	Controlling Variables	Identifying Variables
	Operationally Defining	Identifying Hypotheses
10%	Conservation Reasoning	Combinatorial Reasoning
	Combinatorial Reasoning	Conservation Reasoning, Proportional Reasoning, Controlling Variables, Probability Reasoning, Designing Experiments,
	Designing Experiments	Correlational Reasoning, Identifying Variables, Identifying Hypotheses, Operationally Defining, Graphing & Interpreting Data.

Table 8 (Continued)

5%	Conservation Reasoning	Combinatorial Reasoning
	Combinatorial Reasoning	Conservation Reasoning, Proportional Reasoning, Controlling Variables, Identifying Hypotheses, Operationally Defining, Designing Experiments, Graphing & Interpreting Data.
	Designing Experiments	Correlational Reasoning, Identifying Variables,

Table 9

Results of Testing Hypothesized Subhierarchies
for the Concrete Reasoning Level
Using Dayton and Macready's Probabilistic Method

Sub-Hierarchy	Number of Defining Patterns	α	β	L	df	p	SE_α	SE_β
$(1,6,10,9,8)^{4a}$	12	0.02	0.14	26.72	18	0.087	0.01	0.02
$(1,6,10,9,8)^{4b}$	11	0.04	0.17	40.75	19	0.003	0.02	0.02
$(1,6,2,9,8)^{5a}$	12	0.02	0.13	24.13	18	0.164	0.02	0.02
$(1,6,2,9,8)^{5b}$	11	0.02	0.13	24.60	19	0.187	0.02	0.02
$(1,6,9,8,11)^{6a}$	11	0.03	0.14	21.86	19	0.299	0.02	0.02
$(1,6,9,8,11)^{6b}$	9	0.04	0.15	23.82	21	0.311	0.01	0.02
$(1,10,9,7,4)^{7a}$	8	0.05	0.10	26.44	22	0.237	0.01	0.03
$(1,10,9,7,4)^{7b}$	9	0.06	0.05	29.21	21	0.113	0.01	0.03
$(1,11,9,7,4)^{8a}$	8	0.05	0.11	19.37	22	0.620	0.01	0.03
$(1,11,9,7,4)^{8b}$	9	0.05	0.12	18.79	21	0.597	0.01	0.03
$(1,2,9,7,4)^{9a}$	7	0.06	0.10	37.90	23	0.027	0.01	0.04
$(1,2,9,7,4)^{9b}$	8	0.05	0.09	24.70	22	0.321	0.01	0.03
$(1,3,9,7,4)^{10a}$	8	0.06	0.13	28.06	22	0.187	0.01	0.04
$(1,3,9,7,4)^{10b}$	9	0.05	0.11	20.55	21	0.488	0.01	0.04
$(1,3,9,7,4)^{10c}$	8	0.05	0.16	26.36	22	0.240	0.01	0.03

NOTE: The superscripts on the subhierarchy refer to the respective figures.

Table 10

Results of Comparing Subhierarchies
for the Same Subset of Skills
for the Concrete Reasoning Level

Subset of Skills	Subhierarchies Compared	L2-L1	df2-df1	'p'
(1,6,2,9,8)	5(a) & 5(b)	0.47	1	0.250<p<0.500
(1,6,9,8,11)	6(a) & 6(b)	1.97	2	0.250<p<0.500
(1,11,9,7,4)	8(a) & 8(b)	0.58	1	0.250<p<0.500
(1,2,9,7,4)	9(a) & 9(b)	13.20	1	p<0.0001
(1,3,9,7,4)	10(a) & 10(b)	7.52	1	0.005<p<0.010
	10(b) & 10(c)	5.81	1	0.010<p<0.025

Table 11

Results of Testing Hypothesized Subhierarchies for the Transitional Reasoning Level Using Dayton and Macready's Probabilistic Method

Sub-Hierarhy	No. of Defining Patterns	α	β	L	df	p	SE_α	SE_β
$(1,6,10,9)^{12}$	6	0.20	0.02	6.17	8	0.629	0.10	0.01
$(1,10,11,9)^{13}$	6	0.23	0.02	5.24	8	0.731	0.08	0.01
$(1,10,11,8)^{14}$	6	0.15	0.02	9.45	8	0.317	0.07	0.02
$(6,2,10,5)^{15}$	7	0.01	0.03	6.29	7	0.507	0.05	0.01
$(6,10,4,5,)^{16a}$	7	0.00	0.03	9.57	7	0.223	0.05	0.01
$(6,10,4,5,)^{16b}$	6	0.13	0.04	16.47	8	0.038	0.08	0.02
$(1,10,5,7)^{17}$	6	0.03	0.01	11.18	8	0.204	0.03	0.01
$(6,10,5,7)^{18}$	6	0.02	0.03	1.53	8	0.992	0.04	0.00
$(10,11,9,8)^{19a}$	7	0.15	0.06	7.13	7	0.427	0.06	0.03
$(10,11,9,8)^{19b}$	9	0.08	0.06	4.89	5	0.441	0.06	0.03
$(6,2,10,7,11)^{20}$	11	0.07	0.04	17.20	19	0.575	0.06	0.01

NOTE: The superscripts on the subhierarchy refer to the respective figures.

Table 12

Results of Comparing Subhierarchies
for the Same Subset of Skills
at the Transitional Reasoning Level

Subset of Skills	Subhierarchies Compared	L2-L1	df2-df1	p
(6,10,4,5)	17(a) & 17(b)	6.90	1	0.005<p<0.010
(10,11,9,8)	20(a) & 20(b)	2.24	2	0.250<p<0.500

Table 13

Tests of Vertical Transfer from Subordinate to Superordinate Skills
For Concrete Hierarchy

Transfer from	# who failed Subordinate Skill		# who passed Subordinate Skill		x^2(df=1)	p
	Fail Super.	& Pass Super.	Fail Super.	& Pass Super.		
Skill 1 to 2	6	2	38	5	1.02	0.313
Skill 1 to 8	3	0	17	1	*	0.857
Skill 1 to 9	6	0	33	4	*	0.535
Skill 1 to 11	7	0	38	0	*	-
Skill 6 to 2	9	2	39	8	0.01	0.927
Skill 6 to 8	3	0	20	1	*	0.875
Skill 6 to 9	10	0	38	10	*	0.125
Skill 6 to 11	10	0	36	5	*	0.319
Skill 10 to 8	14	0	14	5	*	0.049
Skill 10 to 7	5	2	9	5	*	0.572
Skill 9 to 7	30	7	17	6	0.43	0.512
Skill 9 to 8	53	3	19	9	10.94	0.001
Skill 2 to 4	4	0	1	3	*	0.071

Note: '*' indicates chi squared statistic not used. Instead, Fisher's exact test was used.

Table 13 (Continued)

Skill 146 to 2	4	2	16	1	*	0.144
Skill 146 to 8	3	0	6	0	*	-
Skill 146 to 9	6	0	16	1	*	0.739
Skill 146 to 11	6	0	17	0	*	-
Skill 247 to 4	3	0	1	2	*	0.200
Skill 9&10 to 7	10	5	4	2	*	0.387
Skill 9&10 to 8	15	0	3	3	*	0.015

Note: '*' indicates chi squared statistic not used. Instead, Fisher's exact test was used.

Table 14

Tests of Vertical Transfer from Subordinate to Superordinate Skills for the Transitional Hierarchy

Transfer from	# who failed Subordinate Skill		# who passed Subordinate Skill		X^2(df=1)	p
	Fail Super.	& Pass Super.	Fail Super.	& Pass Super.		
Skill 9 to 8	10	2	9	6	*	0.187
Skill 10 to 5	1	0	9	4	*	0.714
Skill 10 to 7	1	0	9	4	*	0.714
Skill 10 to 8	1	0	6	3	*	0.700
Skill 10 to 9	0	0	4	6	*	-
Skill 10 to 11	1	0	3	6	*	0.400

Note: '*' indicates chi squared statistic not used. Instead, Fisher's exact test was used.

Table 15

Percentage Pass on Skills Reviewed
for each Vertical Transfer Group

Skill Reviewed	Vertical Transfer Group	Percentage Pass on Skill Reviewed
Skill 1	Skill 1 to 2	84.3
Skill 1	Skill 1 to 8	85.7
Skill 1	Skill 1 to 9	86.0
Skill 1	Skill 1 to 11	84.4
Skill 6	Skill 6 to 2	81.0
Skill 6	Skill 6 to 8	87.5
Skill 6	Skill 6 to 9	82.8
Skill 6	Skill 6 to 11	80.4
Skill 10	Skill 10 to 8	57.6
Skill 10	Skill 10 to 7	66.7
Skill 9	Skill 9 to 7	38.3
Skill 9	Skill 9 to 8	33.3
Skill 2	Skill 2 to 4	50.0
Skill 1 & 6	Skill 1 & 6 to 2	73.9
Skill 1 & 6	Skill 1 & 6 to 8	66.7
Skill 1 & 6	Skill 1 & 6 to 9	73.9
Skill1 & 6	Skill 1 & 6 to 11	73.9
Skill 2 & 7	Skill 2 & 7 to 4	50.0
Skill 9 & 10	Skill 9 & 10 to 7	28.6
Skill 9 & 10	Skill 9 & 10 to 8	28.6

Table 16

Percentage Pass on Skills Reviewed
for each Vertical Transfer Group

Skill Reviewed	Vertical Transfer Group	Percentage Pass on Skill Reviewed
Skill 9	Skill 9 to 8	55.6
Skill 10	Skill 10 to 5	92.9
Skill 10	Skill 10 to 7	92.9
Skill 10	Skill 10 to 8	90.0
Skill 10	Skill 10 to 9	100
Skill 10	Skill 10 to 11	90.0

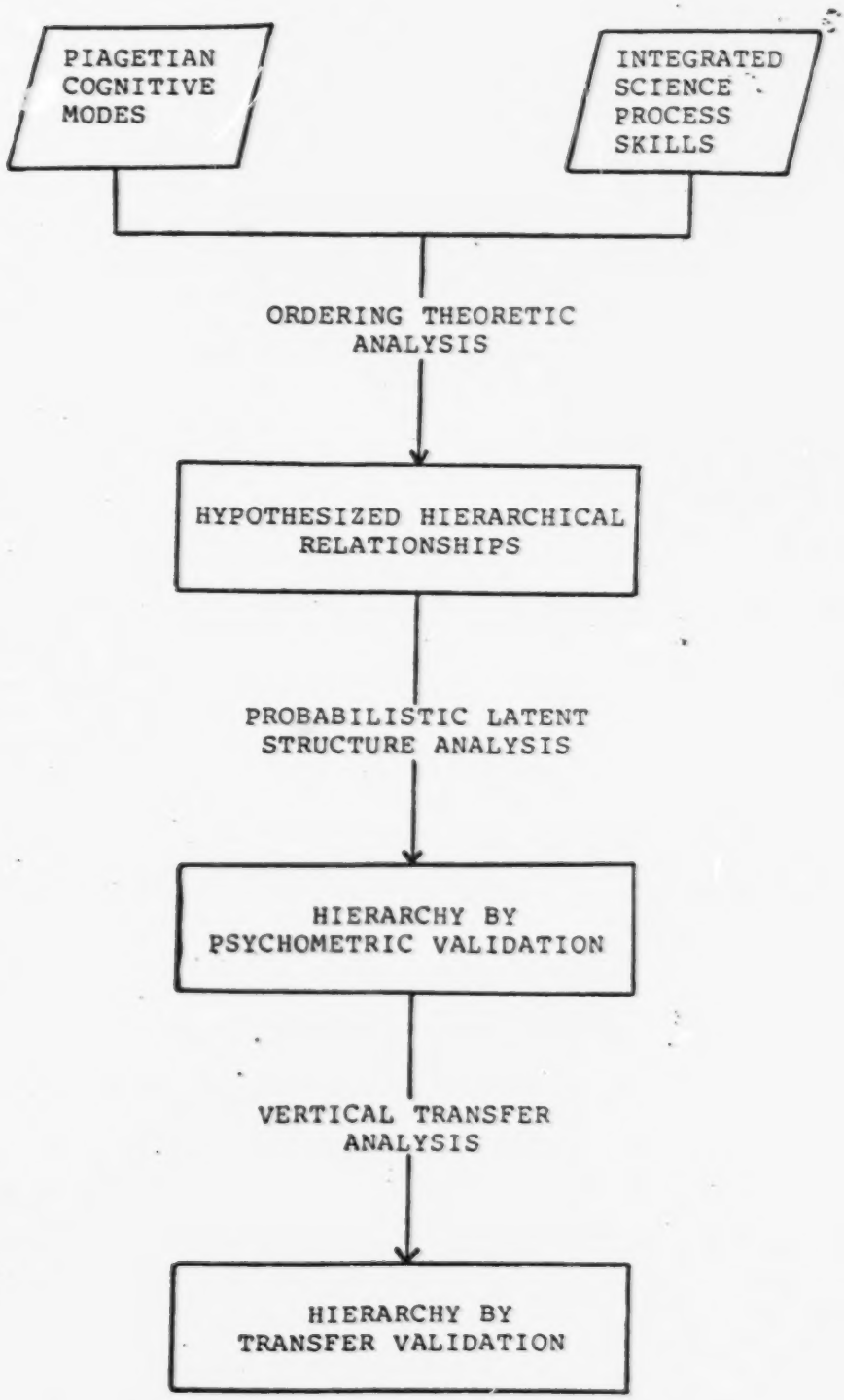
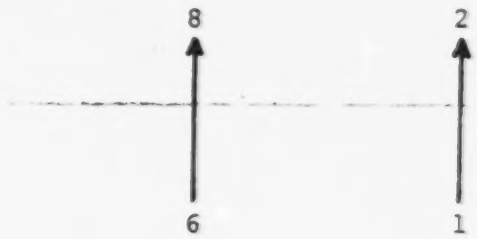


Figure 1. Flowchart Summarizing Research Procedures.

Skill 1 - Conservation Reasoning
Skill 2 - Proportional Reasoning
Skill 3 - Controlling Variables
Skill 4 - Probability Reasoning
Skill 5 - Correlational Reasoning
Skill 6 - Combinatorial Reasoning
Skill 7 - Identifying Variables
Skill 8 - Identifying Hypotheses
Skill 9 - Operational Defining
Skill 10 - Designing Experiments
Skill 11 - Graphing & Interpreting Data

Tolerance Level - 10%



Tolerance Level - 20%

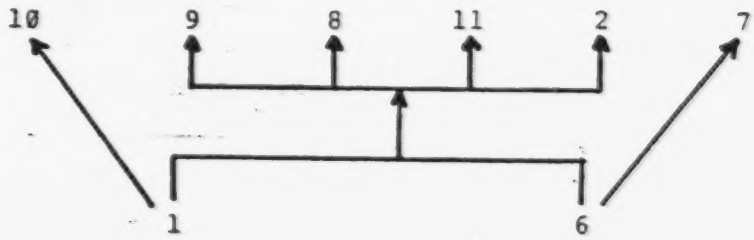


Figure 2: Hypothesized Hierarchy for Concrete Reasoning Level Using Ordering Theoretic Method.

Skill 1 - Conservation Reasoning
Skill 2 - Proportional Reasoning
Skill 3 - Controlling Variables
Skill 4 - Probability Reasoning
Skill 5 - Correlational Reasoning
Skill 6 - Combinatorial Reasoning
Skill 7 - Identifying Variables
Skill 8 - Identifying Hypotheses
Skill 9 - Operational Defining
Skill 10 - Designing Experiments
Skill 11 - Graphing & Interpreting Data

Tolerance Level - 5%

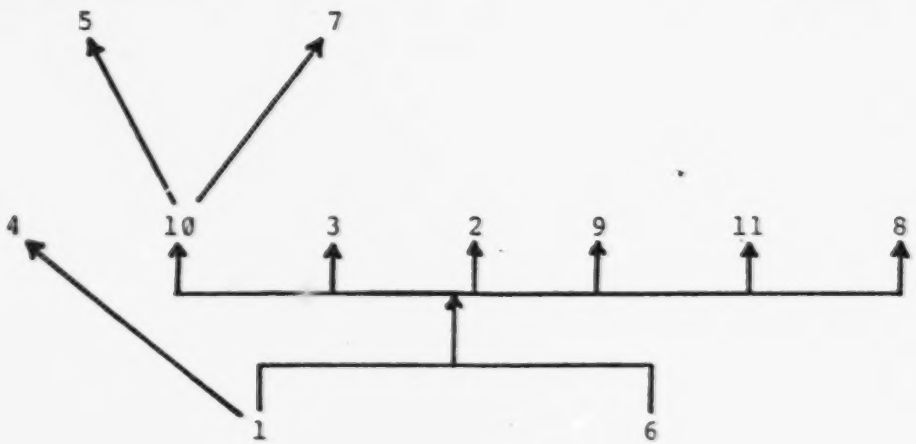
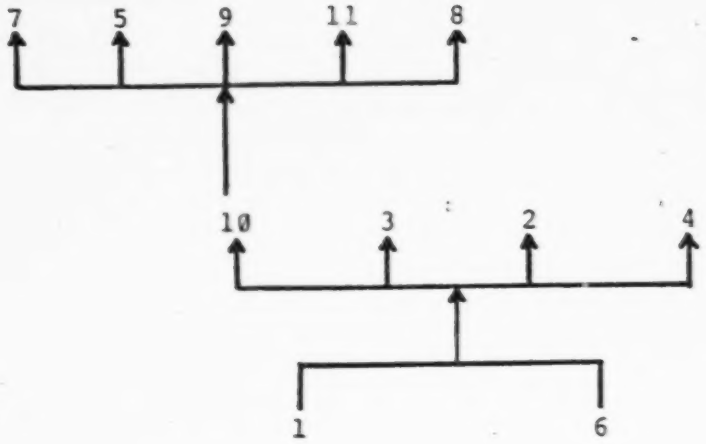


Figure 3: Hierarchical Relationships for the Transitional Reasoning Level Using Ordering Theoretic Method.

Tolerance Level - 10%



Tolerance Level - 20%

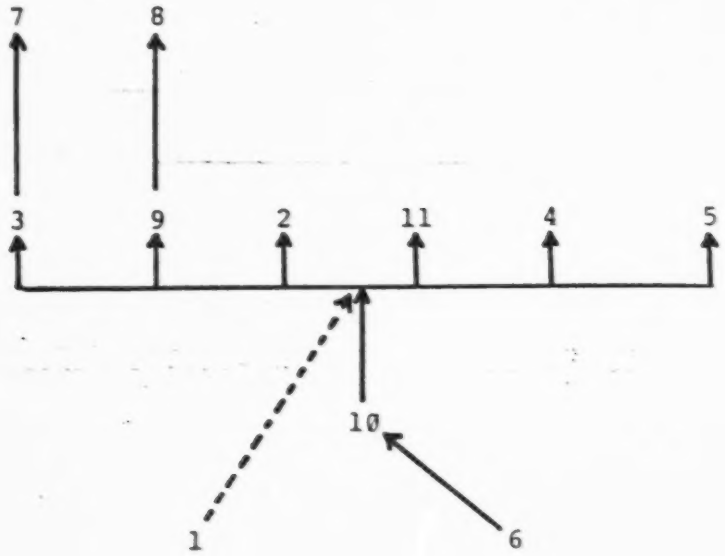


Figure 3: (Continued)

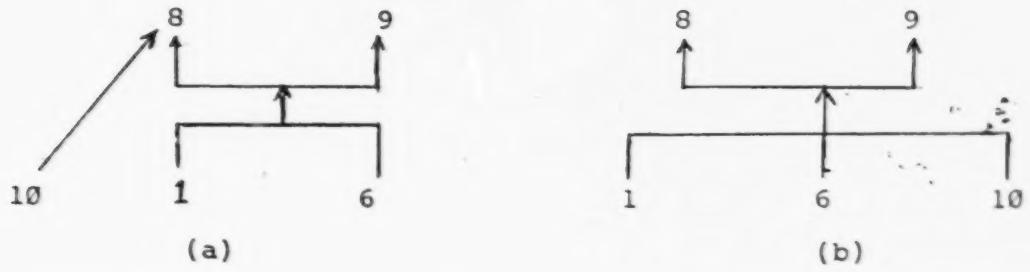


Figure 4. Subhierarchies of Subset of Skills (1,6,10,9,8) for the Concrete Reasoning Level

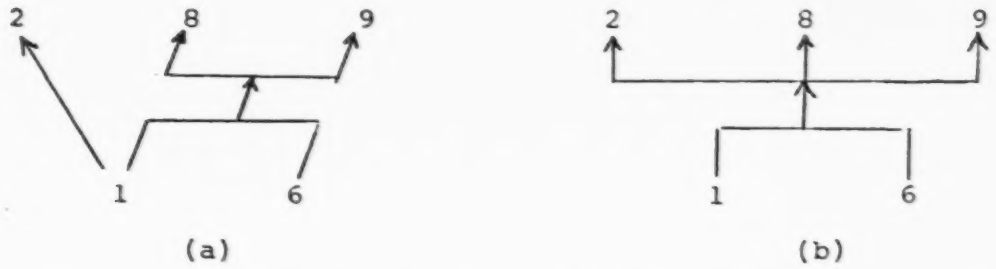


Figure 5. Subhierarchies of Subset of Skills (1,6,2,9,8) for the Concrete Reasoning Level

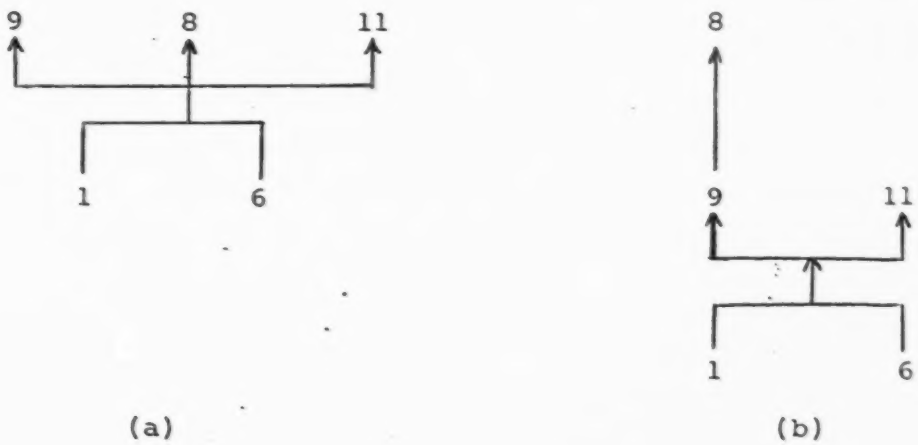


Figure 6. Subhierarchies of Subset of Skills (1,6,9,8,11) for the Concrete Reasoning Level

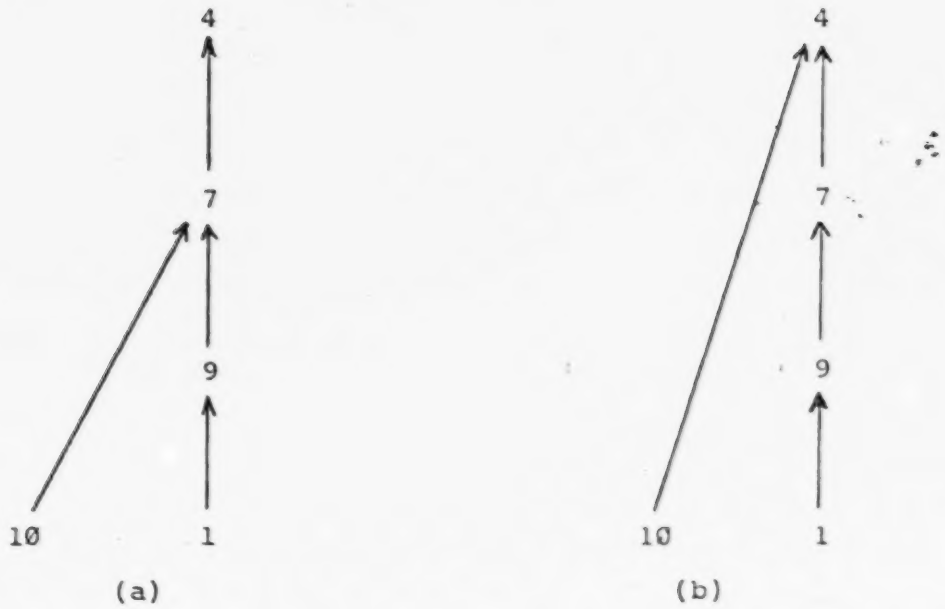


Figure 7. Subhierarchies of Subset of Skills (1,9,10,7,4) for the Concrete Reasoning Level

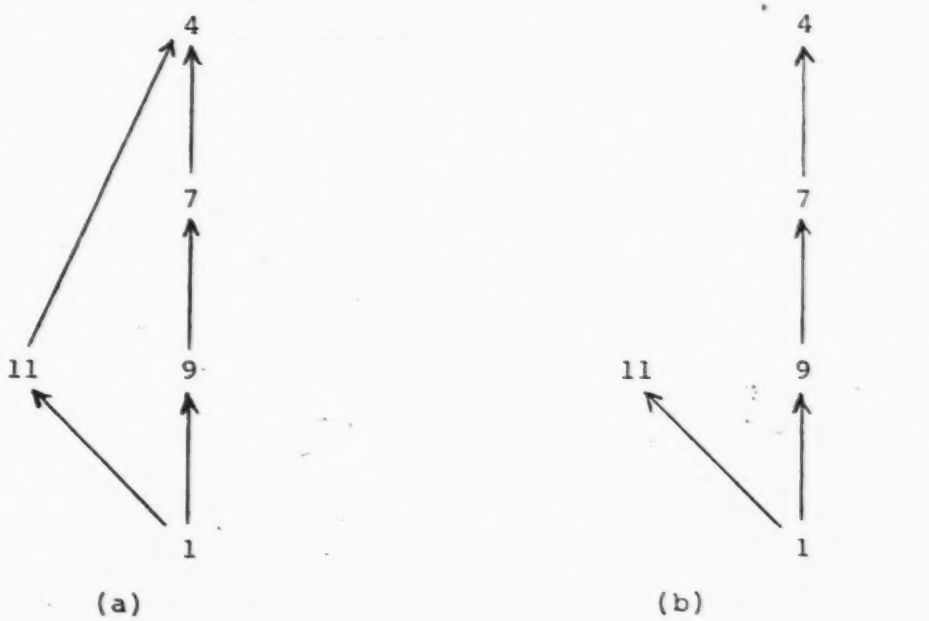


Figure 8. Subhierarchies of Subset of Skills (1,11,9,7,4) for the Concrete Reasoning Level

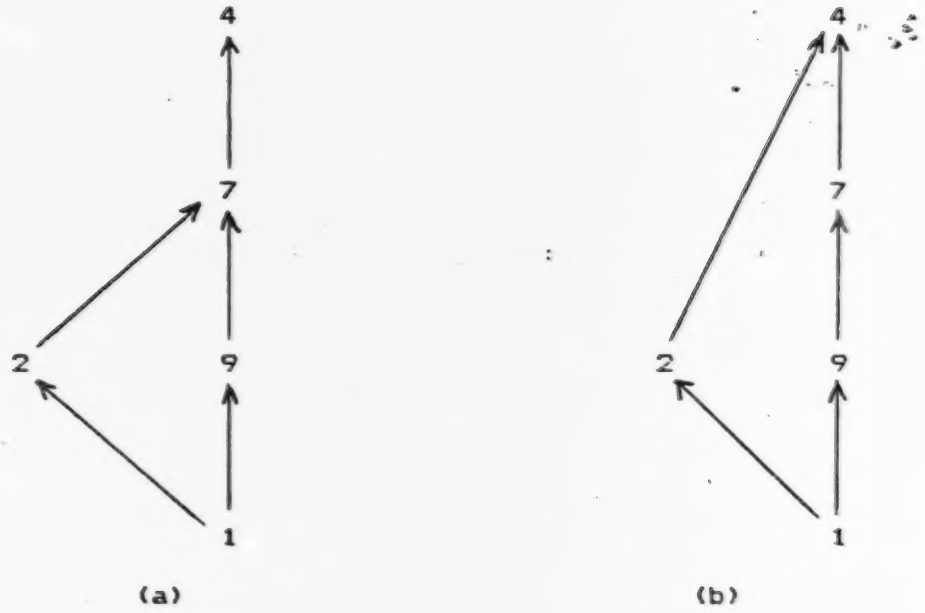


Figure 9. Subhierarchies of Subset of Skills (1,2,9,7,4) for the Concrete Reasoning Level

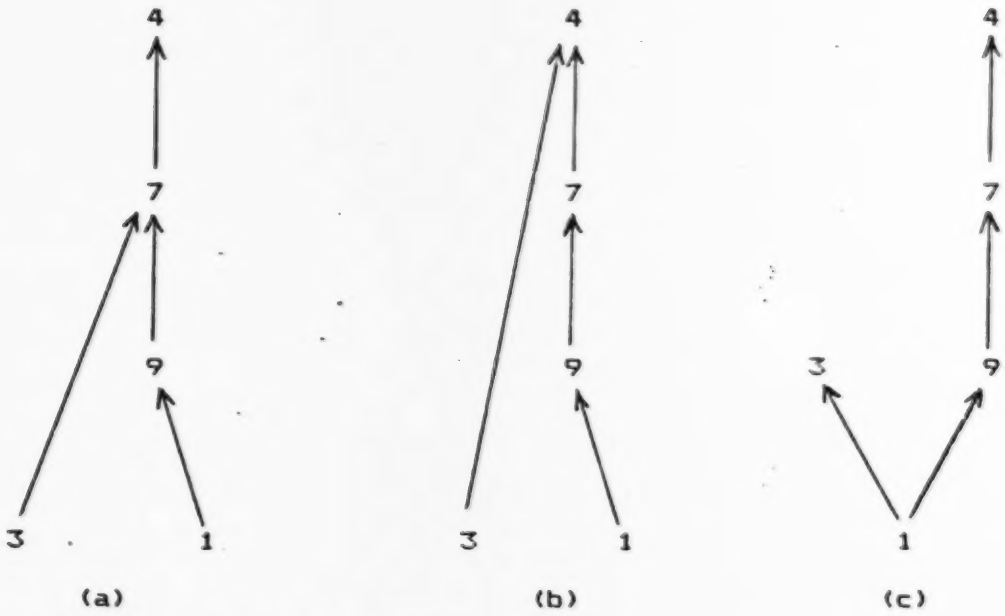


Figure 10. Subhierarchies of Subset of Skills (1,3,9,7,4) for the Concrete Reasoning Level

Skill 1 - Conservation Reasoning
Skill 2 - Proportional Reasoning
Skill 3 - Controlling Variables
Skill 4 - Probability Reasoning
Skill 5 - Correlational Reasoning
Skill 6 - Combinatorial Reasoning
Skill 7 - Identifying Variables
Skill 8 - Identifying Hypotheses
Skill 9 - Operational Defining
Skill 10 - Designing Experiments
Skill 11 - Graphing & Interpreting Data

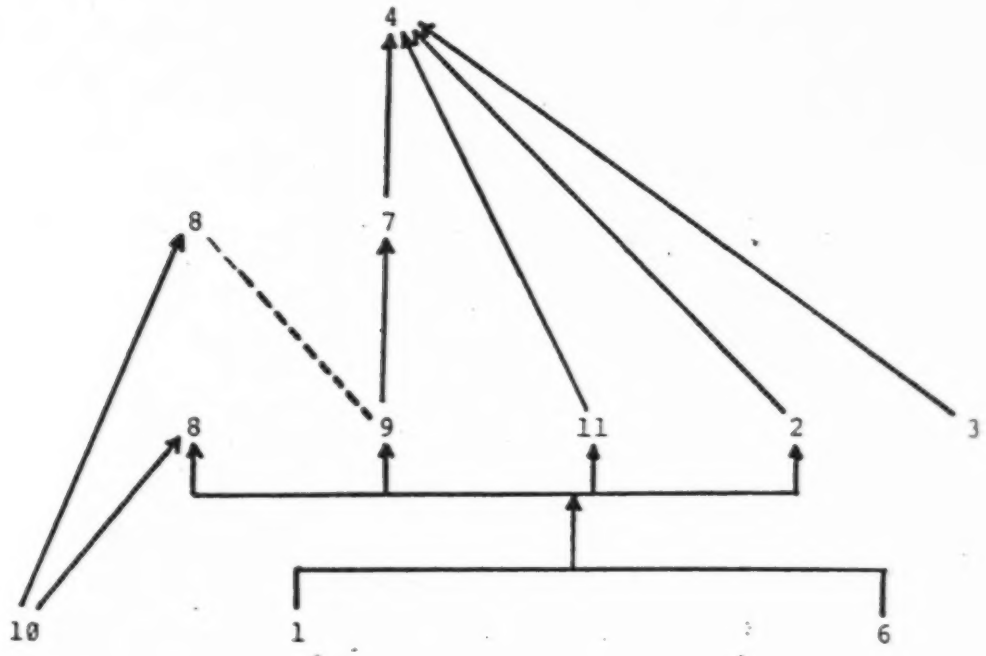


Figure 11: Hierarchy for the Concrete Reasoning Level Derived Using Dayton and Macready's Probabilistic Method

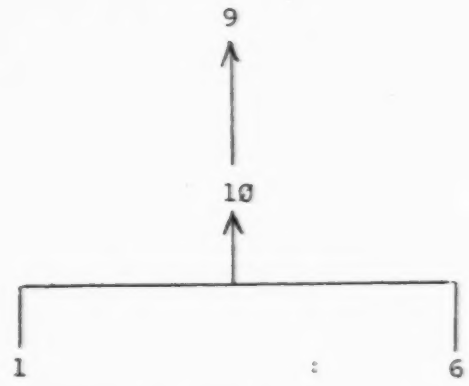


Figure 12. Subhierarchy of Subset Of Skills (1,6,10,9) for the Transitional Reasoning Level

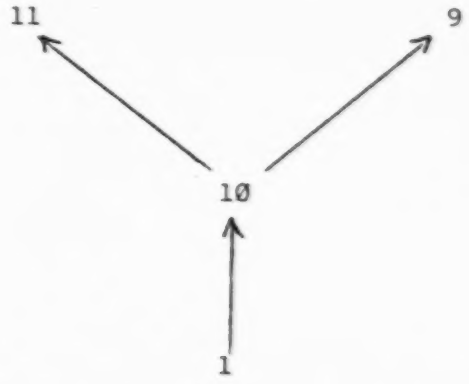


Figure 13. Subhierarchy of Subset Of Skills (1,10,11,9) for the Transitional Reasoning Level

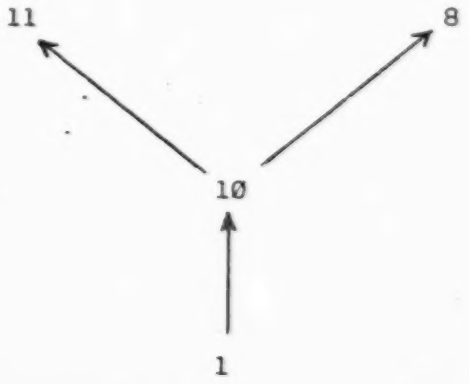


Figure 14. Subhierarchy of Subset Of Skills (1,10,11,8) for the Transitional Reasoning Level

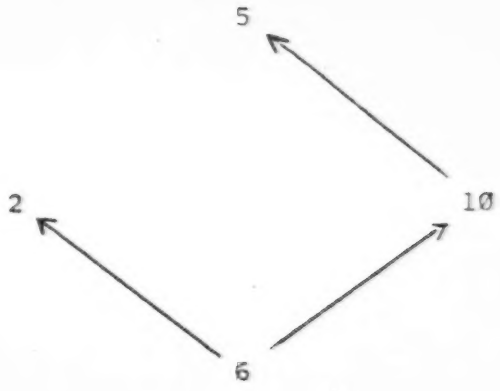


Figure 15. Subhierarchy of Subset of Skills (6,2,10,5) for the Transitional Reasoning Level

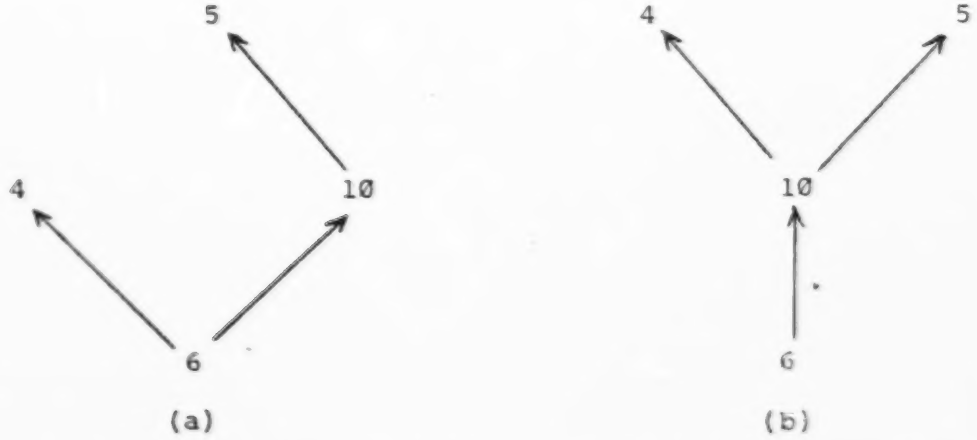


Figure 16. Subhierarchies of Subset of Skills (6,10,4,5) for the Transitional Reasoning Level

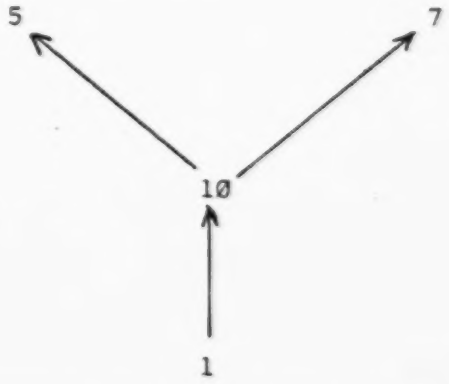


Figure 17. Subhierarchy of Subset Of Skills (1,10,5,7) for the Transitional Reasoning Level

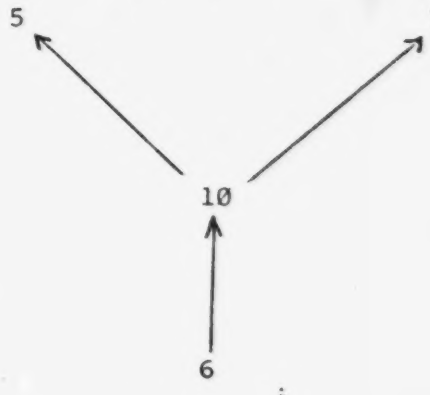
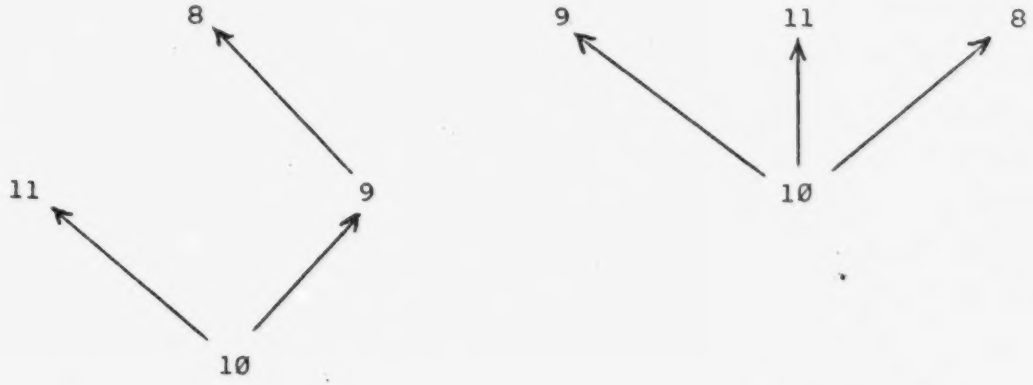


Figure 18. Subhierarchy of Subset of Skills (6,10,5,7) for the Transitional Reasoning Level



(a) (b)

Figure 19. Subhierarchies of Subset of Skills (10,11,9,8) for the Transitional Reasoning Level

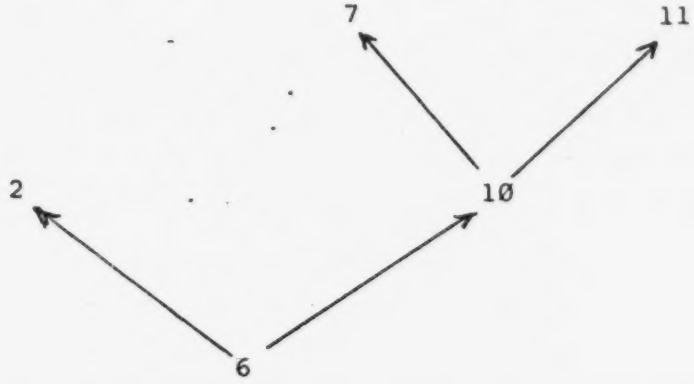


Figure 20. Subhierarchy of Subset of Skills (6,2,10,7,11) for the Transitional Reasoning Level

Skill 1 - Conservation Reasoning
Skill 2 - Proportional Reasoning
Skill 3 - Controlling Variables
Skill 4 - Probability Reasoning
Skill 5 - Correlational Reasoning
Skill 6 - Combinatorial Reasoning
Skill 7 - Identifying Variables
Skill 8 - Identifying Hypotheses
Skill 9 - Operational Defining
Skill 10 - Designing Experiments
Skill 11 - Graphing & Interpreting Data

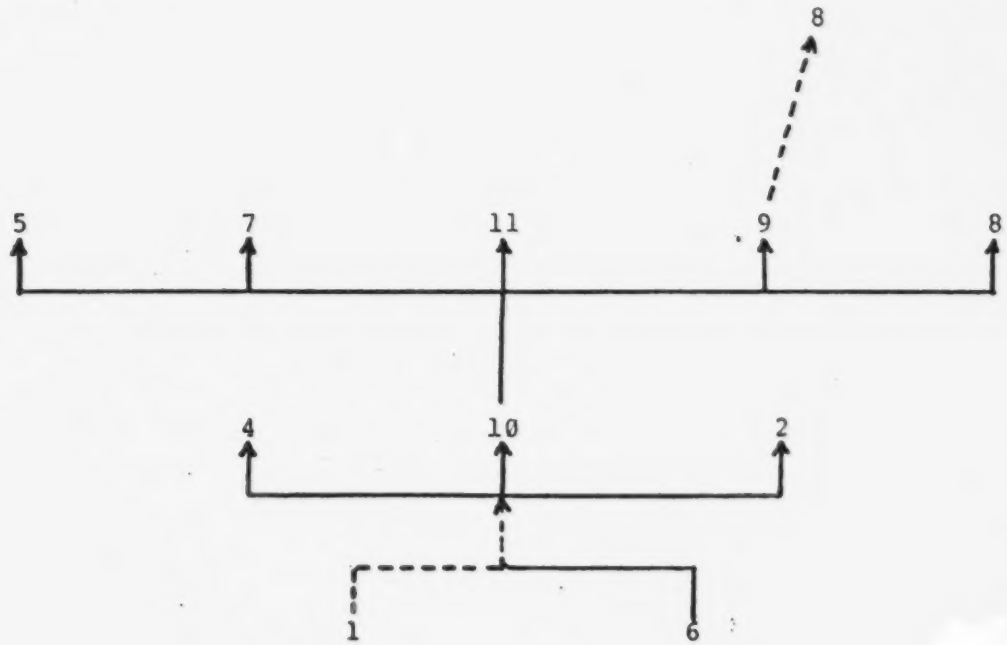


Figure 21: Hierarchy for the Transitional Reasoning Level Derived Using Dayton and Macready's Probabilistic Method